ever, significant changes in τ_{early} occur when the h/l ratio is equal to or less than one. For an h/l ratio change of 50 to 0.5; the value of the maximum S/N decreases by approximately a factor of 2.

Effect of pulse length. The effect of a finite length current pulse can be studied if we assume that the secondary field caused by the current turn-on is equal, but opposite, that of the current turn-off. We further assume that the target response has an exponential decay ($e^{-\tau/\zeta}$) and that the overburden response decays according to a power law ($\tau^{-\nu}$). Thus, the observed S/N will be modified when using a finite current pulse as follows:

$$\text{S/N}_{\text{modified}} = \frac{1 - e^{-\Delta/\zeta}}{1 - \left[1 + \frac{\Delta}{\tau}\right]^{-\nu}} \text{S/N}_{\text{original}}, \tag{5}$$

where the pulse length equals Δ. For targets beneath conductive overburden, equation (5) can be expected to hold after the target response peaks. The modification predicted by equation (5) will, in most cases, lead to a reduction in the S/N.

Voltage measurements. Most EM field systems measure the voltage induced in a receiver coil rather than the detected magnetic field. Because the observed voltage response is proportional to the time derivative of the magnetic field, the response of a target beneath overburden will show a change in sign as the secondary field first grows and then decays. If we again assume an exponential decay for the target response and a power law decay for the overburden, then the late-time change in the S/N for a voltage detector is:

$$\text{S/N}_{\text{modified}} = \left[\frac{\nu\tau}{\zeta}\right] \text{S/N}_{\text{original}} \tag{6}$$

The early-stage voltage response of a target beneath overburden can certainly not be predicted by reference to a free-space model. After the voltage response changes sign (magnetic field peaks), however, a free-space model can reasonably predict the target response. From equation (6), we see that in some circumstances the voltage response may give a higher S/N than the original magnetic field response.

Conclusions

The case of target detection beneath conductive overburden in time-domain EM has been studied for the horizontal coaxial dipole configuration. The main objective of this study was modeling of the target response with consideration of its location beneath the overburden. The anomalous magnetic field response of the target must first build up, because of the screening effects of the overburden, and then decay. The target response will exceed the overburden response for a certain time window which depends on many factors: target-overburden conductance contrast, target depth, target size, and height-to-dipole separation ratio. An enhancement of the target response, over the free-space prediction, is seen with a finite resistivity host rock, but the host rock resistivity was not found to be critical in determining target detection capability. An EM system with a large h/l ratio was found to have the best target detection capability, which diminished as the h/l ratio lessened. A finite length current pulse will generally not enhance the S/N. Measurement of the voltage response, rather than the magnetic field response, can yield a higher S/N at certain late times.

While the particular system configuration studied is not widely used, the conclusions should be applicable in other situations. The effect of conductive overburden in time-domain EM is to delay the time of detection of a conductive target beneath it. Thus an explorationist can enhance his prospects of finding a buried conductor by changing his survey parameters to ensure signal detection in the appropriate time window.

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Effects of Vertical Contacts on Time-Domain Electromagnetic Sounding MIN 1.8

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We investigated the anomalous effects of a vertical geologic contact on transient electromagnetic sounding (TEM) measurements. The magnetic field responses for this simple feature were studied using a laboratory scale model assembled at the University of California, Berkeley. Models were made for (1) a discontinuous conductive surface layer (surface contact), and (2) a surface contact with a deeper conductive layer present. These models were studied using five TEM sounding configurations: (1) central loop, (2) fixed-separated loops oriented perpendicular to the contact, (3) fixed-separated loops parallel to the contact, (4) fixed transmitter loop-variable offset receiver, and (5) electrical dipole transmitter-variable offset receiver.

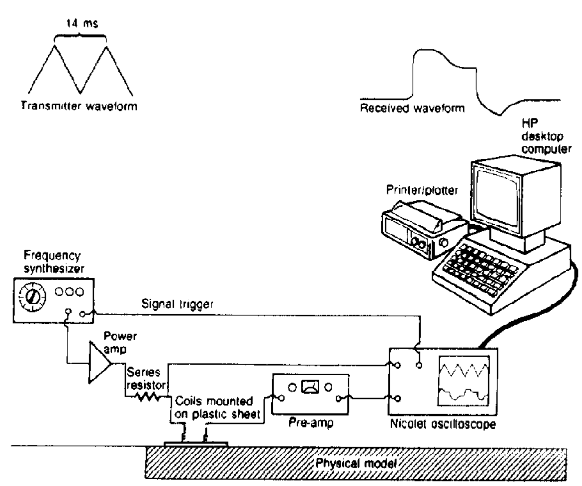

FIG. 1. Scale model system.

Results for model 1 indicate that the contact response depends on the geometric arrangement of the sounding configuration in addition to the model parameters. EM systems involving widely spaced transmitters and receivers (system 4) generally see a broadly shaped anomaly most prevalent at late times and centered on the resistive side of the contact. The central loop system (system 1) which has no transmitter-receiver offset produces a narrow anomaly centered on the conductive side of the contact that is more prevalent at early time. The fixed separation systems (systems 2 and 3) and the electrical dipole (system 5) see a combination of early time and late time anomalies with relative magnitudes that depend somewhat on the transmitter-receiver separation.

If a deep layer is added below the contact (model 2) then the observed response for all systems is the superposition of the layered model response and the contact response. This model was used to compare the TEM systems for the purpose of deciding which system provided the best deep layer response for stations near the contact. The 5 TEM sounding systems were compared by calculating the ratio of the maximum contact anomaly to the maximum response for a deep layer at each station and then plotting the results as profiles. These plots show that the contact anomaly can be over thirty times larger than the deep layer response and that all systems except system 1 (central loop) exhibit significant contact effects up to 1 km from the boundary. The best system is the central loop which exhibits the smallest and narrowest contact anomaly; it occurs at early time whereas the layered response is at late time. The worst system is the electrical dipole which has a small layered response and a large broad contact anomaly that is present at both early and late times.

Introduction

A laboratory model study was undertaken at the University of California to investigate the effects of vertical contacts on EM sounding data. One goal of the project was to gain an understanding of the distribution of secondary fields and induced currents in the presence of vertical contacts in the subsurface resistivity structures. Surface inhomogeneities have long presented problems in the interpretation of EM soundings. The signal due to these is often larger than the desired signal from the layered resistivity section and at present it is not possible to separate the effect of lateral inhomogeneities from the desired sounding data. The result is that interpretation of soundings made near contacts or inhomogeneities is usually erroneous and can be misleading. The problem has so far proved intractable with numerical models because of the associated expense and limited accuracy (Lee and Morrison, 1985). This paper gives a description of the University of California, Berkeley's Engineering Geoscience scale model facility and presents results for five commonly used EM sounding configurations over simple contact models. Based on these results some criteria are given for evaluating the effects of vertical contacts for each system considered.

Measurement system

Scale model measurements are made in the time domain using a triangular transmitter waveform and induction coil receivers.

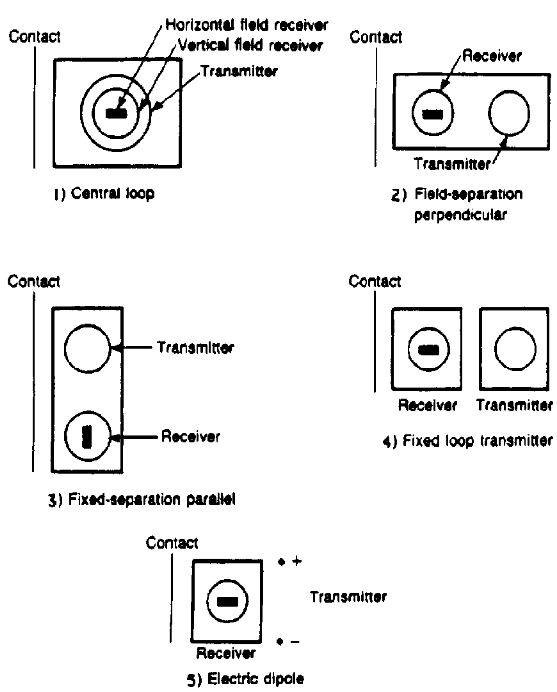

FIG. 2. Diagram showing sounding configurations used.

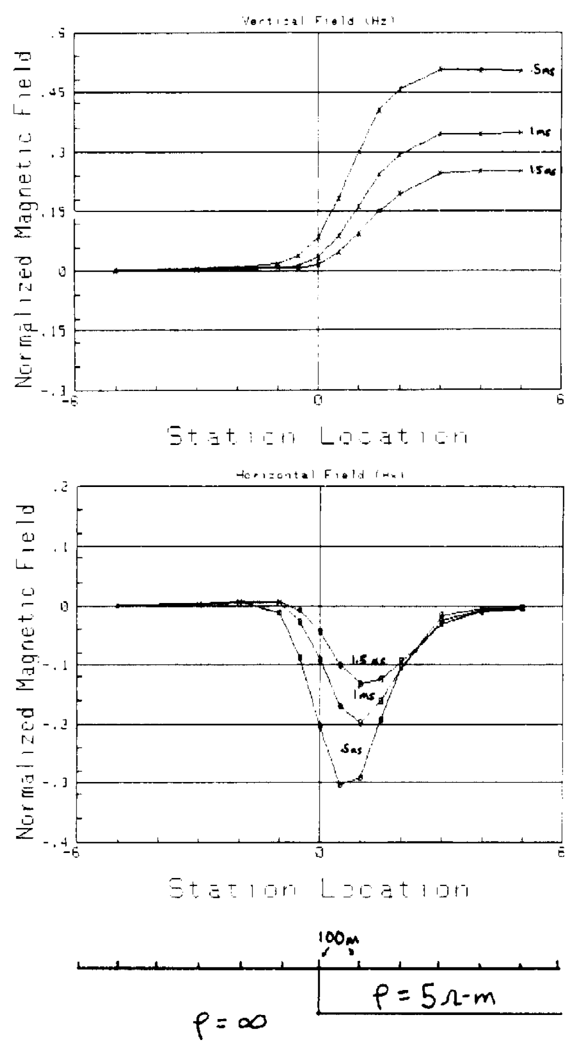

FIG. 3. Top, middle time (5–2 ms) vertical magnetic field profile over simple contact model 1; bottom, middle time (5–2 ms) horizontal magnetic field profile over simple contact model 1.

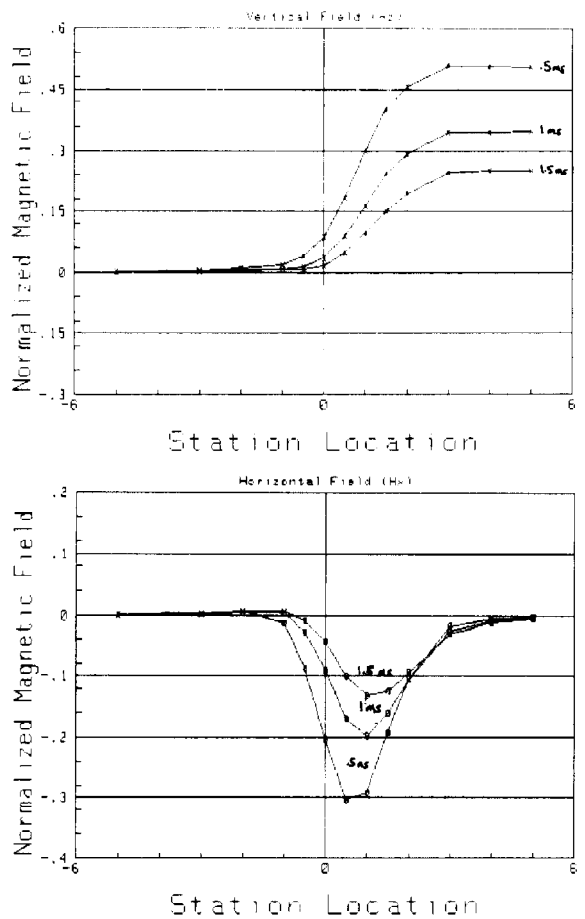

FIG. 4.

This combination is equivalent to a system based on a time varying magnetic field from a square wave source. By adjusting the dc level at the receiver coil the signal appears very similar to the magnetic field produced by a step change in transmitter current (West et al., 1984). For this study the magnetic field step response is used rather than the commonly measured time derivative of this quantity (impulse response) for several reasons. First it is easier to acquire late time data for magnetic fields since they decay more slowly than the in-time derivative. Secondly it is a simple task to compute the time derivative from field data but performing the reverse calculation is much more difficult, especially for noisy data. Finally, our experience is that the time derivative is generally a more complicated waveform than the field quantity and is therefore more difficult to interpret.

The modeling system shown schematically in Figure 1 consists mostly of commercially available electronic instruments. Aluminum is used for the modeling material. The primary field is created by a frequency synthesizer connected to a power amplifier whose output is connected to a small transmitter coil through a series resistor. This system is capable of generating up to 10 amp of current for several different waveforms at frequencies from dc to 10 kHz. For this study we used a 7 Hz triangular waveform at 5–10 amp. The receiver consists of 2 small coils connected to a preamplifier and then to a 2-channel digital oscilloscope. Data are digitized at 10 μs intervals, averaged, and stored in the scope buffer prior to processing by a desk top computer. The computer averages the data in time windows, does calibration corrections, prints, and plots results. Final results are stored on cassette tapes. Measurements are made by manually moving the coils to specified positions on the model and initiating a time stack on the oscilloscope. The data are visually inspected on the scope, prior to acceptance or rejection. A station typically requires 1–5 minutes of averaging before random error is acceptably low.

Vertical contact study

The system described above was used to study 3 vertical contact models in 5 TEM sounding configurations. The models considered are (1) surface vertical contact and (2) vertical contact over a deep layer. Measurements were made at a scale of 1/10 000 (1 cm = 100 m) using aluminum sheets to represent the conductive layers and air as the host medium. The sounding configurations used are (1) central loop, (2) fixed-offset loops oriented perpendicular to contact, (3) fixed offset parallel to contact, (4) fixed transmitter loop-variable receiver offset, and (5) electrical dipole transmitter (Figure 2).

Results for model 1 indicate that the contact response depends on the geometrical arrangement of the sounding configuration in addition to the model parameters. EM systems involving widely spaced transmitters and receivers (system 4) generally see a broadly shaped anomaly which is most prevalent at late times and is centered on the resistive side of the contact. Central loop system 1 which has no transmitter-receiver offset produces a narrow anomaly centered on the conductive side of the contact that is more prevalent at early time. Fixed separation systems 2 and 3 and the electrical dipole (system 5) see a combination of early time and late time anomalies with relative magnitudes that depend somewhat on the transmitter-receiver separation.

To illustrate the magnetic field behavior across a vertical contact, we present magnetic field profiles over a simple vertical contact (model 1) using the central loop configuration (system 1). Figures 3a and b show vertical and horizontal magnetic field profiles across the contact for intermediate times (5–2 ms). The vertical field displays a smooth transition from the slow decay over the sheet to the abrupt free space response over the contact. The transition almost completely occurs within 500 m of the contact although for late times the transition zone may extend 700–800 m from the boundary. On the resistive side of the contact the anomaly dies away quickly until it has virtually disappeared within 300 m.

In contrast to the vertical field, the horizontal magnetic field for this configuration exhibits no response far away from the contact because it is completely related to the currents induced near the contact. The anomaly is a slightly asymmetrical positive peak centered on the conductive side of the contact. The amplitude of the anomaly decreases with time from a maximum of 30 percent of the primary field and the position of the maximum migrates away the contact at later times. The anomaly is steeper on the side closer to the contact and it displays a small negative overshoot across the contact.

If a deeper layer is added below the contact (model 2), then we observe that the response for all systems is the superposition of the layered model response and the contact response. This model was used to compare the TEM systems for the purpose of deciding which system provided the least distorted layered response for stations near the contact. The 5 TEM sounding systems were compared by calculating the ratio of the maximum related to the contact anomaly to the maximum response for the corresponding layered model, each station, and then plotting the results on a profile. These plots show that for some systems the contact anomaly can be over 30 times larger than the deep layered model response and that all systems except system 1 (central loop) exhibit significant contact effects up to 1 km from the boundary. The best of the systems considered is the central loop which exhibits the smallest and narrowest contact anomaly; it occurs at early time whereas the layered response is at late time. The worst sounding configuration is the electrical dipole (system 5) which has a small layered response and a large broad contact anomaly that is present from early to late time.

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